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The Control Strategy of Cold Storage and Energy Savingin Subway Tunnel Is Realized by Piston Wind

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ABSTRACT

Based on the data comparison results of field investigation, the energy saving problem of piston wind in the new subway tunnel is analyzed in depth, and some opinions are put forward, which are verified by field test.

Outline

China 's subway ventilation and air conditioning system is complex and ignores the use of natural cold source, train piston ventilation is not included in the category of energy saving ; a large number of artificial cold and heat sources are used. There are many problems, such as large space occupation, high construction investment, high construction difficulty, high energy consumption of train and station operation, complex operation, rapid temperature rise of subway tunnel environment, serious environmental damage, large maintenance volume, poor maintainability, difficult renovation and high operating cost. The purpose of this invention is to use the existing subway automatic control system to only modify the software of the automatic control system (that is, to change the control mode and strategy) or only to improve the optimal operation mode, without increasing the investment, or only a small amount of sensors and transmitters and other detection devices. Scientific and reasonable improvement and optimization of the operation mode and control strategy of the subway tunnel ventilation system can effectively reduce the tunnel ambient temperature, greatly reduce the operation energy consumption of the train and station ventilation and air conditioning system, reduce the utilization rate of the electromechanical equipment system, improve the integrity rate of the electromechanical equipment system and extend the service life.

Current Subway Tunnel Ventilation Situation

The initial temperature of the subway tunnel is approximately equal to the temperature of the soil layer, which is close to the annual average temperature of the local weather (lower than the ground outdoor temperature). Through the tunnel data monitored by the temperature-sensitive optical fiber designed by subways in various places, we found that after the opening and operation of subways throughout the country, the summer temperature of the tunnel soon rose to about 7℃ ~ 10℃ higher than the outdoor temperature on the ground. Too fast temperature rise leads to a significant increase in the energy consumption of subway trains and stations (heat and platform door heat conduction) in summer. In the southern city of Guangzhou Metro and Shenzhen Metro, refrigeration and air conditioning must be turned on for trains in November in winter ; therefore, it is necessary to adjust and control the temperature of the tunnel, adopt a scientific tunnel ventilation mode, and use the natural cold source of the tunnel to store cold. It is best to maintain the annual average temperature, or reduce the temperature rise of the tunnel by 3℃ to 7℃, and the air conditioning season can greatly reduce the energy consumption of subway trains and stations.

The previous design generally believes that the heat emitted by the train (braking resistance, wheel-rail friction, on-board air conditioner) will cause the tunnel temperature to rise, and adopts the method of increasing the piston tuyere + mechanical ventilation to increase the tunnel ventilation capacity for cooling.

Ground outside the station	Upward tunnel	Downward tunnel	platform	station hall
31.3℃	34.2℃	33.9℃	25.2℃	26.6℃

Figure 1. The temperature value of the platform, tunnel and ground of a traditional subway line

With the continuous development, improvement and improvement of the technical level of subway trains, the application of energy regenerative braking inverter recovery technology, the train cancels the configuration function of the braking resistor, and the heat of the train is greatly reduced. Through full investigation and actual operation monitoring, testing and empirical analysis, it is found that the external heat source introduced by the piston wind + mechanical ventilation of the train tunnel is far more than the heat generated by the train itself. The excessive temperature rise of the tunnel is not entirely caused by the heat generated by the train, but the excessive introduction of external atmospheric heat (source) in summer, resulting in excessive temperature rise of the tunnel and high energy consumption of the subway. Therefore, it is necessary to change the previous concept, improve the design, construction and operation mode of tunnel ventilation system, and adjust and control the environment of tunnel.

Ground outside the station	Upward tunnel	Downward tunnel	platform	station hall
31.5℃	30.1℃	29.5℃	25.2℃	26.6℃

Figure 2. An energy feedback system subway line

At present, the ventilation of subway tunnel basically focuses on the use of train piston wind and mechanical ventilation (tunnel ventilation system, rail top and rail bottom heat removal system) to control tunnel cooling and dilute CO_2 concentration. As an auxiliary method for temperature control of interval tunnel, train piston wind maintains full open condition for a long time. In the new line equipped with the regenerative braking inverter recovery function, due to the cancellation of the braking resistance of the train, the atmospheric temperature of the external ground environment in summer is higher than the temperature of the tunnel inside the subway. When the piston air valve is still opened according to the maximum (piston) ventilation capacity, a large number of external atmospheric heat sources are introduced as the train travels in and out of the station. This heats the tunnel, causing the tunnel temperature to rise rapidly in the early stage of subway operation, and the train air conditioning load increases the traction energy consumption (the train air conditioning energy consumption accounts for about 24 % of the train traction energy consumption)

Especially in some non-closed platform lines : there is no isolation firewall above the platform door, such as Beijing Line 4 and Line 8. After the high-temperature piston wind enters the tunnel, the cooling capacity of the platform is extracted along the way, which leads to the increase of ventilation and air conditioning energy consumption in the subway station, and the comprehensive energy consumption is amazing.

Engineering Design Principle of Tunnel Temperature Energy Saving Control

The regenerative inverter recovery technology of regenerative braking has led to a revolutionary change in the train braking mode : from the traditional ' energy feedback braking + resistance braking + brake shoe braking ' to the new ' energy feedback braking + brake shoe braking

The piston wind ventilation of subway trains that have implemented the regenerative braking inverter recovery technology is included in the scope of energy-saving regulation and control ; by adopting the asymmetric train piston wind natural ventilation control strategy method, the cold source is stored in the morning and evening in summer. Make full use of the underground tunnel space of the subway as a natural cold source storage space to achieve energy saving.

In summer, by reducing the piston wind and external ventilation, the introduction of external heat is reduced ; the temperature of the tunnel is close to the average temperature of the perennial climate and the soil temperature, and a temperature balance is naturally established.

In spring and autumn, the atmospheric temperature difference between daytime and nighttime is used to cool down : when the external temperature is higher than the internal temperature of the tunnel, the piston air valve is controlled to reduce the opening degree, or the bilateral piston of the platform is controlled to be operated by a single piston, the internal circulation is increased, the exchange of internal and external air is reduced, and the introduction of external heat is reduced ; when the external temperature is lower than the internal temperature of the tunnel in the morning and evening, the piston air valve is controlled to increase the opening degree, or the single piston operation is controlled to change into double piston operation, the exchange volume of internal and external air is increased, the tunnel temperature is reduced, and the energy consumption of fresh air in subway (train and station) air conditioning is further reduced.

Tunnel Temperature Control Project Design

Summer Daytime

In summer, when the external temperature rises during the day and is higher than the internal temperature of the tunnel, the ventilation volume inside and outside is reduced. Through the opening control of the piston air valve, a small amount of ventilation with the outside is realized to avoid excessive carbon dioxide, ensure the air quality in the tunnel, ensure that the temperature in the tunnel is lower than the outdoor atmospheric temperature, and provide a low-temperature working environment for the train air conditioner to reduce the energy consumption of the train air conditioner.

A part of the self-circulation in the tunnel reduces the outward discharge of cooling capacity in the tunnel ; make the piston wind air volume and wind pressure to establish a balance.

Ensure that the temperature of the piston wind (as the station fresh air) entering the station through the platform door is lower than the outdoor atmospheric temperature (using the cold energy accumulated in the tunnel soil layer in winter).

When extreme high temperature weather occurs in summer, the air valve of the tunnel ventilation system can be closed during the non-peak period of passenger flow during the day, so as to realize (closed) closed operation and avoid excessive introduction of external heat sources.

Summer Morning And Evening

In summer, when the external temperature decreases in the morning and evening, and is lower than the internal temperature of the tunnel, the ventilation volume inside and outside is increased to ensure that the temperature in the tunnel is lower than the outdoor atmospheric temperature.

Through the piston wind and external ventilation, reduce the concentration of carbon dioxide and humidity, to ensure the air quality in the tunnel.

Winter

Fully open the piston wind valve (south of the Yangtze River), close the ventilation part of the tunnel 's own circulation and the ventilation part with the station, increase the ventilation volume of the piston wind and the outside, so as to reduce the temperature in the tunnel and accumulate cold energy.

Anti-freezing in extremely cold areas (north of the Yellow River). When the temperature in the tunnel is lower than 5℃, it is necessary to close the tunnel ventilation to achieve internal circulation (closed) closed operation and avoid excessive introduction of external cold sources.

Spring and Autumn

The overall trend of summer and winter is very obvious, and the temperature fluctuation in spring and autumn is relatively large, between summer and winter ; however, in spring, the humidity of the external atmosphere is very high, and the tunnel needs to control the temperature and reduce the humidity at the same time. In autumn, the external atmosphere is dry, and the humidity control requirements in the tunnel are relatively low, only the cooling needs to be considered.

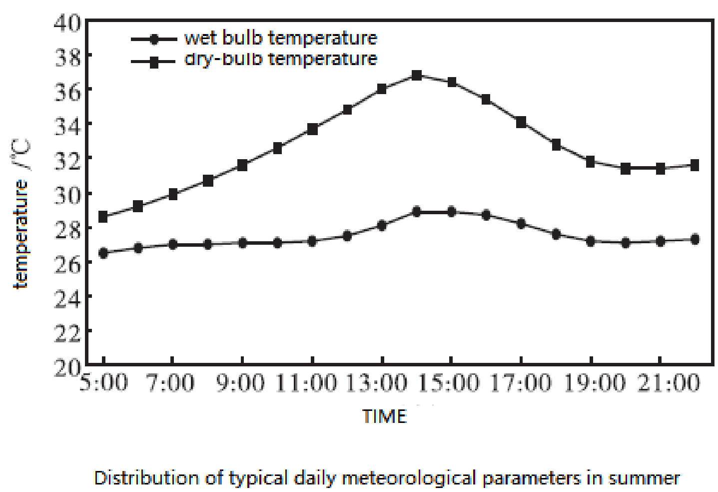

Figure 3. The distribution map of meteorological parameters of typical days in summer

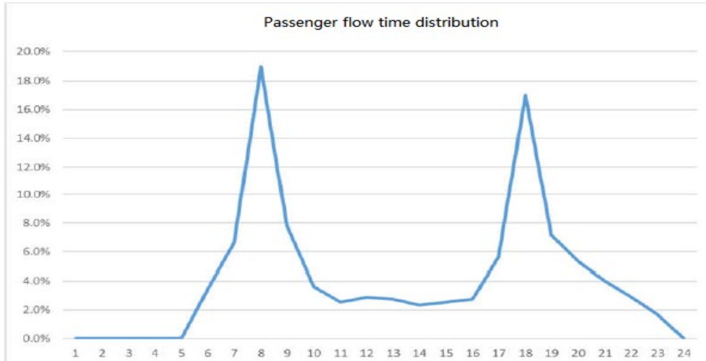

Figure 4. Typical daily passenger flow changes

In spring and autumn, according to the outdoor atmospheric temperature (curve), the temperature and CO2 concentration in the tunnel, the peak and non-peak passenger flow, the peak and non-peak traffic density and passenger capacity, the train piston wind ventilation opening mode is adjusted every day.

When the outdoor atmospheric temperature is higher than the temperature in the tunnel, the piston wind ventilation rate with the outdoor should be reduced to reduce the introduction of external heat.

When the outdoor air temperature is lower than or equal to the temperature (humidity) in the tunnel, the ventilation rate of piston wind should be increased.

When the outdoor atmospheric humidity is higher than the humidity in the tunnel and is close to saturation, the temperature in the tunnel is lower than the outdoor atmospheric temperature. In order to avoid condensation in the tunnel, the piston wind ventilation with the outdoor should be reduced to reduce the introduction of external water vapor.

Piston Wind Pressure Control Strategy in Tunnel

It should be noted that in the experimental verification stage of this project design, it is found that the sliding door in the fully enclosed design of the platform (the fire-proof partition wall and partition are arranged above the platform door, and the natural ventilation between the tunnel and the platform is cut off) is greatly affected by the piston wind pressure during the trip of the switch action after the train arrives at the station. The failure rate of single door switch is positively fitted with the piston wind pressure.

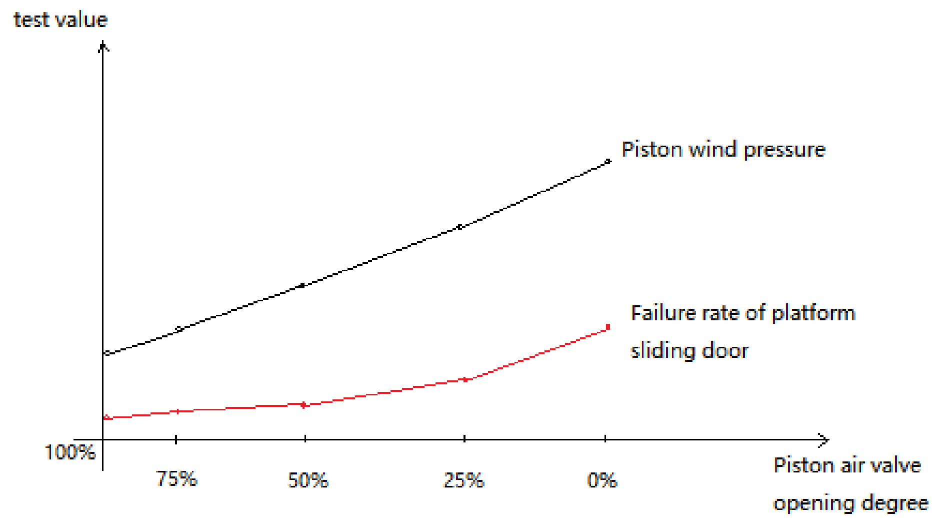

Figure 5 : The relation curve of fault rate with opening angle and wind pressure

Although this problem can be solved by manually adjusting the sliding door of the platform door to preset the opening and closing torque curve. But it also reflects the cost of expanding the piston wind pressure in the fully enclosed design of the platform.

The air pressure control and air volume control strategy of the piston wind in the tunnel have the following control modes :

ALL open piston air valve ventilation (fully open double piston air valve ventilation) mode P1 ; in this mode, the exchange volume of internal and external air volume is the largest, and all the air pressure is discharged. as shown in Fig.6 below :

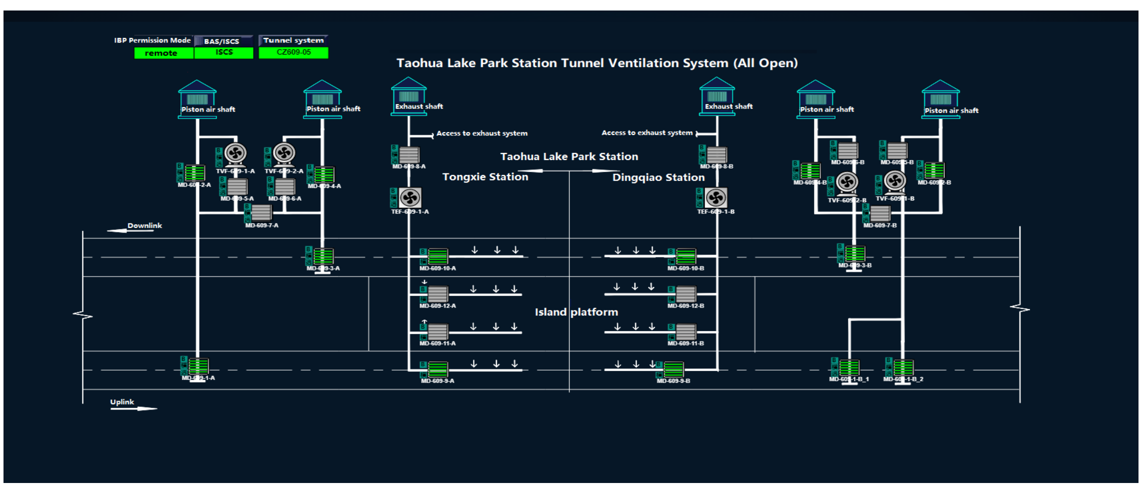

Figure 6. All open model

Semi-open piston air valve ventilation (only open up / down single piston air valve ventilation) + full open up and down ventilation valve mode (internal circulation ventilation) mode P2 ; in this mode, the internal circulation ventilation is a part of the internal circulation ventilation, the exchange volume of internal and external air volume is slightly lower, which belongs to the medium ventilation volume, and the wind pressure is balanced by the internal circulation. as shown in Fig.7 below :

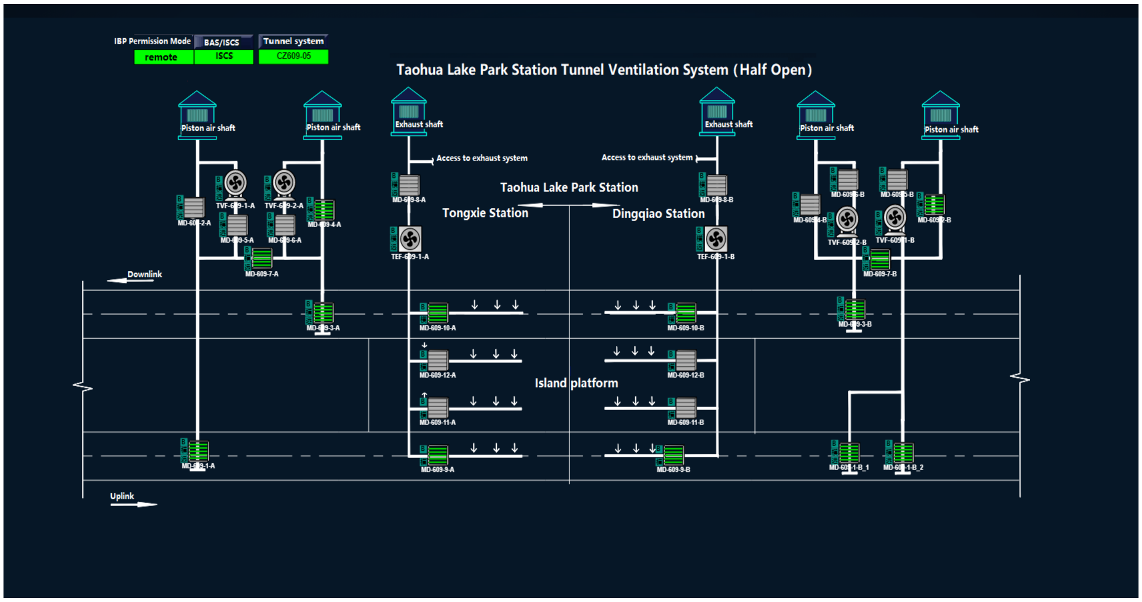

Figure 7. Semi-open model

ALL closed piston air valve ventilation (fully closed double piston air valve ventilation) + fully open up and down ventilation valve + station part ventilation mode P3 ; this mode belongs to the fully closed internal circulation ventilation mode, which relieves pressure through internal circulation and station.as shown in Fig.8 below :

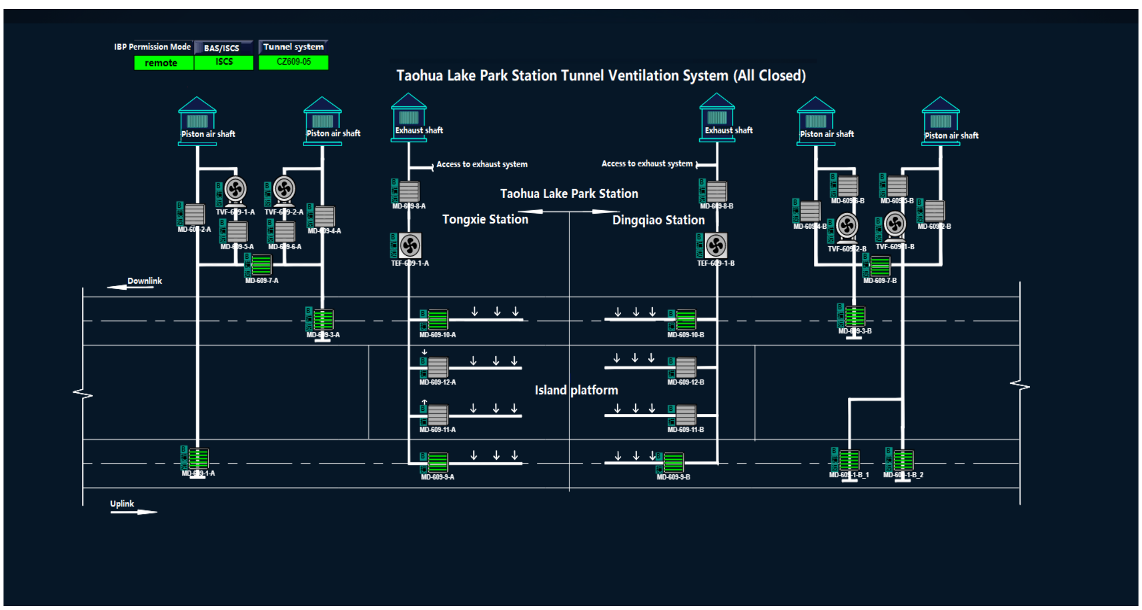

Figure8. All closed model

Temperature Control Strategy in Tunnel

In summer, when the external temperature is higher than 37℃, in winter, when the external temperature is zero (the temperature in the tunnel is lower than 5°C), and in the moldy rain season, the semi-open piston air valve or partial and full closed operation is adopted to avoid the introduction of excessive heat and cold and water vapor.

Summer

Temperature and humidity control strategy in high temperature and moldy rain season. In summer, when the external high temperature exceeds 37℃ ~ 40℃, the outdoor temperature is higher than the temperature in the tunnel, or the relative humidity in the rainy season exceeds 95 %, the piston air valve is fully closed. The operation mode, corresponding to the wind pressure P3 control mode, avoids the introduction of too much heat, or avoids the introduction of too much moisture, resulting in condensation in the tunnel.

The temperature difference between day and night is large.

Before the morning peak, the double-piston air valve full-opening (double-piston) control mode can be adopted, corresponding to the wind pressure P1 control mode ;

During the day, the semi-open piston air valve (single piston) control mode can be adopted, corresponding to the wind pressure P2 control mode ;

At night, the double-piston air valve is fully open (double-piston) control mode, corresponding to the wind pressure P1 control mode ;

When the temperature in the tunnel is lower than the external atmospheric temperature during the day and night, the semi-open piston air valve (single piston) control mode can be used throughout the day, corresponding to the wind pressure P2 control mode.

When the temperature in the tunnel is higher than the external atmospheric temperature during the day and night, the full-open double-piston air shaft (double-piston) control mode can be used throughout the day, corresponding to the wind pressure P1 control mode.

Spring and Autumn

When the temperature in the tunnel is not much different from the external atmospheric temperature, the full-opening double-piston air shaft control mode can be used throughout the day, corresponding to the wind pressure P1 control mode.

Winter

When the ambient air temperature is higher than zero, and the temperature in the tunnel is higher than the ambient air temperature, the control mode of all-day full opening (all-day double piston air shaft) can be adopted, corresponding to the wind pressure P1 control mode.

Winter low temperature control strategy. When the ambient air temperature is lower than zero throughout the day, avoid introducing too much cold energy and freeze the fire hose or equipment in the tunnel.

The semi-open (single-piston air shaft) control mode can be adopted, corresponding to the wind pressure P2 control mode.

After the comprehensive use of the above control strategy, the subway can effectively reduce the tunnel temperature and achieve a lot of energy saving without increasing investment or a small amount of software modification.

The Priority of Temperature, Humidity, Carbon Dioxide Concentration and Wind Pressure in The Tunnel

The regulation and control of temperature, humidity, carbon dioxide concentration and wind pressure need to meet the requirements of the field environment. Considering the excessive ventilation of the piston wind in the subway tunnel in reality, the flexible temperature control strategy can be further refined and realized with the help of model analysis. The concentration of carbon dioxide, wind pressure, humidity and health environment are also accompanied by flexible control strategies.

According to the following order : humidity > temperature > wind pressure > carbon dioxide concentration.

The humidity in the tunnel should produce condensation, which should cause system and equipment failure, involving safety, with the highest priority ;

The priority of temperature control and wind pressure control, temperature control is the priority, taking into account the wind pressure control (platform door failure rate), overrun priority adjustment control.

The measured actual carbon dioxide concentration in the tunnel under various working conditions is far lower than the control standard of 400ppm, so it is not necessary to consider this factor.

When the external climate is windy or windy, fog and haze and other bad weather, affecting the internal air quality of the subway, closed operation or small opening operation can be used to reduce the internal and external air exchange, to ensure the internal air quality, using PM2.5 or PM10 as control parameters.

Evaluation of Engineering Design Effect

The above control strategy can further reduce the train traction energy consumption by reducing the ambient temperature in the tunnel (the train air conditioning energy consumption accounts for 20 % of the train traction energy consumption). The train air conditioning load is expected to be reduced by 30 %, and the train traction energy consumption is expected to be reduced by about 6 %.

In addition, with the decrease of the temperature in the tunnel, the cold air in the tunnel can also circulate a part to the station. The non-closed platform line of the subway in the northern city can be used as the cold source of the station, which can further reduce the energy consumption of the station air conditioning system.

Taking Changsha Metro Line 6 as an example, the closed operation control strategy is adopted in the summer tunnel to stabilize the temperature of the tunnel in summer at about 25℃ ~ 26℃, and only a set of ventilation and air conditioning system is needed at the A and B ends of the station, which satisfies the heating of the station (passengers and electromechanical equipment) and the heating of the tunnel and the train (on-board air conditioning + wheel-rail friction).

The highest temperature of some tunnels in Hangzhou Metro in summer is 39℃, and the lowest is only 32℃, but the highest temperature in outdoor daytime is usually only about 35℃. The total size and capacity of the ventilation and air conditioning units installed on the train are basically the same as the size and capacity of the ventilation and air conditioning system of the station. Hangzhou Metro has considered the use of energy regenerative braking inverter recovery technology in the traction power supply system in the fourth phase of the planning, and the corresponding matching piston wind control strategy mode is of great significance.

At present, the focus of subway energy saving is on station ventilation control, ignoring the energy saving of train ventilation and air conditioning, as well as the energy saving of interrelated effects. Tunnel piston wind has a great impact on the energy saving of subway station ventilation and air conditioning system. This engineering design research makes up for this deficiency.

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